NASA TECHNICAL TRANSLATION

NASA TT F-15,998

PERFORMANCE IMPROVEMENT THROUGH CONTROL CONFIGURED VEHICLE CONCEPT

G. Löbert

Translation of "Leistungserhöhung durch Reglergestützten Flugzeugentwurf," Deutsche Gesellschaft für Luft- und Raumfahrt, Jahrestagung, 5th, Berlin, West Germany, Oct. 4-6, 1972, DGLR No. 72-094 and UFE-895-72(Ö), 27 pp

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 NOVEMBER 1974

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TT F-15,998		

4. Title and Subtitle	5. Report Date
PERFORMANCE IMPROVEMENT THROUGH CONTROL CONFIGURED VEHICLE CONCEPT	November 1974
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
G. Lobert, Messerschmit-Bölkow-Blohm GmbH	
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
Leo Kanner Associates Redwood City, California 94063	NASw-2481
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Translation
National Aeronautics and Space Administration, Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Leistungserhöhung durch Reglergestützten Flugzeugentwurf," Deutsche Gesellshaft für Luft- und Raumfahrt, Jahrestagung, 5th, Berlin, West Germany, Oct. 4-6, 1972. DGLR No. 72-094 and UFE-895-72 (Ö), 72 pp

16. Abstract Demonstration of the possibility of obtaining high potential power increases at only small additional costs by employing artificial instead of natural stabilization. It is shown that if the requirement of static aerodynamic stability is eliminated, the drag polars and thus flight performance can be significantly improved. This improvement occurs mainly in the form of an increase in specific excess power at high lift coefficients and in an increase in the attainable maximum lift coefficients. The dynamic flight characteristics of such aircraft can be made equal to or better than the characteristics of aerodynamically stable aircraft through appropriate artificial stabilization. By incorporating suitable redundancies and other provisions, the flight safety of conventional mechanically controlled aircraft can be achieved.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

Table of Contents

PERFORMANCE IMPROVEMENT THROUGH CONTROL CONFIGURED VEHICLE CONCEPT

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1. Introduction /1*

In conventional aircraft design, the size and position of wings and control surfaces and the arrangement of these surfaces with respect to the aircraft's center of gravity are selected in such a manner that the aircraft exhibits satisfactory maneuverability in all degrees of freedom in any possible flight situation and that the various modes of elastic and flight-mechanics oscillation have an adequate natural stability. It is self-evident that the performance and costs-effectiveness of an aircraft are considerably impaired by the necessity of satisfying these requirements.

If the control system of an aircraft is fully incorporated into the design process, these performance losses can be greatly reduced. Thus dispensing with inherent longitudinal stability allows aircraft weight to be distributed between wings and control surfaces in a manner favorable in terms of drag and lift; the elimination of inherent directional stability permits a reduction in rudder area, and eliminating inherent stability with respect to elastic modes of oscillation permits a reduction in structural weight and the avoidance of limitations on operating range. If the requirement for inherent stability is eliminated, new possibilities for aircraft design arise which promise further performance enhancement.

* Numbers in the margin indicate pagination in the foreign text.

The control system can also be used to reduce the airframe load due to gusts, flight maneuvers or landing surges, making it possible to lengthen service life or increase savings in weight. Finally, the control system makes it possible to improve piloting and disturbance behavior and the flight characteristics of the aircraft (control and stability augmentation, direct lift and side-force control, ride smoothing).

The control configured vehicle concept differs from conventional design in the consistent exhaustion of the performance potential made possible by the complete integration of aircraft and autopilot (cf. Fig. 1).

2. Performance Enhancement Through the Elimination of Inherent Longitudinal and Lateral Stability /2

2.1. General

2.1.1. Longitudinal Stability and Induced Drag

Fig. 2 shows the basic dependence of induced drag divided by $K \cdot C_L^2$ upon the distribution of total lift between wing and elevator for various ratios of elevator and wing area. On the left, the set of curves apply to the tailed aircraft, while the curves on the right refer to the canard configuration.

The graph shows that in both configurations, induced drag decreases as aircraft weight is shifted from the forward surface, under a greater aerodynamic load, to the less heavily loaded rear surface. The limit of stability which has been drawn in gives the rearmost position of the center of gravity with which sufficient inherent stability still exists. For both aircraft, we see that the region of lowest induced drag can be reached only with the aid of an artificial stabilization system. The same applies also to the flying wing configuration.

It must be noted that the minimum in drag increases with increasing elevator area ratio and reaches its highest value in the tandem aircraft ($A_{fore} = A_{aft}$). The flying wing achieves the absolute minimum in induced drag -- provided the center of gravity is located at the neutral point or somewhat aft of it.

This general consideration is based on the assumption of a constant K factor for both lift surfaces. It is apparent that the effectiveness of shifting the center of gravity aftward increases as the lift-dependent drag of the forward surface increases with respect to that of the aft surface.

2.1.2. Position of Center of Gravity and Trimmed $C_{L\,max}$

Dispensing with inherent aerodynamic longitudinal stability allows trimmed C_{Lmax} to be enhanced considerably. Fig. 3 shows trimmed C_{Lmax} as a function of the distribution of total lift between wing and elevator, i.e., as a function of the position of the center of gravity. $C_{Lmax,trim}$ can be increased by shifting the center of gravity aftward, until the C_{Lmax} of the elevator is reached.

2.1.3. Measured Lift and Drag Polars /3

The trimmed drag polar for a combat aircraft model ($\Lambda_{wing} \sim 3$, $\Phi_{wing} \sim 30°$, $A_{elev}/A_{wing} \sim 0.35$) is shown in Fig. 4 for two different stability indices. We see that shifting the CG aftward by 0.25 $l\mu$ causes an appreciable improvement in the trimmed polar. At medium C_L values, a 25% reduction is found in induced drag. This gain increases further at higher C_L values.

The improvement in the lift curve due to a reduction in the stability index by 0.25 can be seen from Fig. 5. At $\alpha = 15°$, C_L is 23% higher than the corresponding value for the stable CG position. The increase in trimmed C_{Lmax} is 28%.

2.2. Potential Increases in Combat Aircraft Performance

Dispensing with inherent aerodynamic longitudinal stability produces higher flight performance in existent aircraft and lower takeoff weights in new designs. In the following, graphs are presented and explained which have been plotted with the aid of a design computer program developed at MBB.

2.2.1. Existent Aircraft

Fig. 6 shows the change in specific range and in specific flight time accompanying a change in center of gravity, which represents a direct measure of longitudinal stability, for a typical combat aircraft ($W/A = 70\ lb/ft^2$, $\Lambda_{wing} \sim 3$, $\Phi_{wing} \sim 40°$). Shifting the center of gravity aftward by 17% $l\mu$, for example, reduces fuel consumption per flight minute by 5.3% and consumption per km by 1.7%.

Specific excess power ($SEP = (T - D)/W \cdot V$) at $Ma = 0.9$ and 8000 ft altitude is plotted in Fig. 7 for three different CG positions as a function of maneuverability and load factor. Shifting the center of gravity aftward produces great improvements in climbing and longitudinal acceleration capabilities, particularly for high load factors.

Fig. 8 shows change in landing speed as a function of center of gravity position for the existent aircraft. A CG shift aftward by 17% $l\mu$ produces a rise in C_{Lmax} which leads to a 7.9% reduction in landing speed.

Fig. 9 shows the rise in trimmed C_{Lmax} which can be achieved /4
in the case of the F4E Phantom by shifting the center of gravity aftward about 10% $l\mu$. The relative increase in C_{Lmax} is 24% in the subsonic region and 45% in the supersonic region.

2.2.2. New Designs

The following results were calculated on the assumption of a constant mission radius and satisfaction of the minimum maneuvering performance requirements of

$$20 \text{ ft/sec SEP at } n_z = 4;\ Ma = 0.6;\ H = 8000 \text{ ft and}$$
$$0 \text{ ft/sec SEP at } n_z = 1;\ Ma = 1.6;\ H = 36{,}000 \text{ ft}$$

and scaling of the power plant for a given area load of 70 lb/ft^2.

Fig. 10 shows the effect of CG position and the stability index on takeoff weight, broken down into airframe, fuel, power plant and remaining items. For example, takeoff weight can be reduced 3.3% by shifting the center of gravity 0.17 $l\mu$. The pronounced variation in power plant weight with stability index should be given particular attention here. It changes 8.2% when the center of gravity is shifted aftward by the specified amount.

The effectiveness of shifting the CG aftward is highly dependent upon the maneuvering performance required. If very high load factors are to be steadily flyable at high altitudes, the savings in takeoff weight can amount to as much as 10%.

The takeoff weights of new designs with scaled power plants are plotted in Fig. 11 as a function of the ratio of elevator to wing area for various longitudinal stability indices. Thus the weight minimum for the artificially stabilized flying wing and the maximum in takeoff weight for the tandem aircraft agree with the aerodynamic information presented in Section 2.1.2. For comparison, data are included in Fig. 11 for a delta and a canard aircraft.

The different distances between the three curves for the tailed aircraft are explained by the fact that the aircraft in the two cases for which $\Delta X/l\mu = +0.3$ and $+0.07$ are dimensioned by subsonic maneuvering requirements (high C_L) and for the two cases in which $\Delta X/l\mu = +0.07$ and -0.1, by subsonic horizontal flight requirements (low C_L).

2.3. Enhancement of Transport Aircraft Performance /5

In transport aicraft, the wing generally exhibits a smaller lift-dependent drag $dC_D/d(C_L^2)$ than the elevator. For this reason, the effectiveness of drag reduction caused by shifting the CG aftward is less than for combat aircraft. On the other hand, large nose-heavy pitching moments are connected with the latest high-speed profiles (roof-top, rear loading), so the control surface loads of modern transport aircraft are shifted toward higher lift coefficients from the outset.

On the other hand, the favorable effect of shifting the CG aftward on trimmed C_{Lmax} or $C_{Lbuffet}$, which depends only upon $\Delta Xs/r_H$, is fully utilized in the transport aircraft.

According to [7], dispensing with inherent longitudinal stability allows a weight savings of 1.9% of takeoff weight in the case of a new transport design.

2.4. Enhancement of Performance by Dispensing with Aerodynamic Lateral Stability

If the CCV concept is applied to the axis of yaw, rudder area can be reduced to the point that controllability can just barely be ensured in extreme flight states (power plant failure, landing in side wind). The savings in structural weight and undesirable drag thereby achieved is manifested in the flight performance of a given aircraft or the takeoff weight of a new design.

For long-range bombers with a given mission radius, takeoff weight is reduced by about 4% if inherent lateral stability is dispensed with [6]. In the case of the combat aircraft, the corresponding savings in weight is about 2.5% [2]. The small gain can be attributed to the smaller contribution of the rudder to weight and drag.

2.5. The Control and Regulating System of the Artifically Stabilized Aircraft (cf. [2])

The artificial stabilization of an aircraft requires a fully electrical control system. Such control systems have already been used in VTOL combat aircraft (VJ 101, VAK 191), although only for short-term use.

Fig. 12 shows a fully electrical control and regulating system schematically for the axis of pitch of an artificially stabilized aircraft in its simplest form. The angle of attack, measured with suitable sensors, is communicated via the autopilot to the electrohydraulic actuating cylinder, which adjusts the elevator proportionally to α. The coefficient determining static longitudinal stability, $\partial C_M/\partial\alpha$, can thereby be brought to the desired value. /6

Weathercock stability is regained in the same manner. The necessary flight safety is achieved by redundancy (multiple use of individual elements in the control circuit, in addition to the power supply).

2.5.1. Safety and Reliability Requirements

Fig. 13 shows the derivation of safety requirements for the electrical control system of an artificially stabilized combat aircraft. Statistically, a hazardous situation occurs every 10^4 flight hours when jet aircraft are used tactically. The contribution of technical causes is 25% to 50% here. If we assume that 10% of these technical causes can be attributed to the control system, we obtain an empirical value of $3 \times 10^{-6}\ h^{-1}$ for the hazard rate due to flight control. This value, which is also to be required for the combat aircraft with artificial stability, corresponds to a crash rate of 1 or $2 \times 10^{-6}\ h^{-1}$, meaning one crash every 3 to 6 years for a fleet of 500 aircraft used with 300 hours/year.

If the same failure rate is assumed for the hydraulic system as for flight control, the quantitative requirement obtained for the system made up of control + hydraulics is: failure rate with respect to flight safety = $6 \times 10^{-6}\ h^{-1}$.

2.5.2. Degree of Redundancy

The requirement derived in Section 2.5.1 with respect to the failure rate of the control and regulating system, including power supply, can be achieved with various combinations of the multichannel signal acquisition and processing subsystems with redundant electrohydraulic actuator cylinders. Fig. 14 allows various possible regulator/actuator combinations to be evaluated with respect to their relative costs and flight safety. It is found here that of those control systems which satisfy the required failure rate in practical terms, the system with a four-channel regulator and duo-duplex actuators yields the lowest cost.

2.6. Flight Safety with Artificial Stabilization /7

Within MBB-UF's running study on "Combat Aircraft with Artificial Stability," the firm of Bodenseewerk Gerätetchnik designed a triaxial fly-by-wire control system with a quadruplex signal processing unit and duo-duplex electrohydraulic actuator cylinders in detail. The comprehensive reliability and failure analyses subsequently performed on this control system yielded a hazard rate of $7.59 \times 10^{-6}\ h^{-1}$, a probability of $1.92 \times 10^{-6}\ h^{-1}$ that saving the pilot is no longer possible (double hydraulic failure or failure of three servo channels), and a mission failure probability (return after the first malfunction) of $4.67 \times 10^{-3}\ h^{-1}$. Thus the artificially stabilized aircraft equipped with a duo-duplex control and regulating system achieves the flight safety of a conventional combat aircraft.

Fig. 15 shows the time after which the load factor has changed by 6 g in case of total control system failure, for the most unfavorable case, Ma = 0.9, H = 0, as a function of the instability index. As can be seen, saving the pilot is possible only for a low instability index. This fact has been taken into consideration in the loss rate given above.

2.7. New Design Possibilities

If the control and regulating system is incorporated into the design process for an aircraft, new design possibilities are opened up which promise further performance enhancement.

An example of this is the jet-controlled combat aircraft with sliding wings shown in Fig. 16a, in which all tail elements have been dispensed with.

If the concept of artificial stability is applied to swing-wing aircraft, the position of the swing bearing can be selected without considering the shift in the neutral point. If the bearing is shifted into the fuselage, structural and aerodynamic advantages over the inherently stable swing-wing aircraft result.

By installing an extendible canard control-surface assembly on an inherently stable transport aircraft (cf. Fig. 16b), it is possible to increase C_{Lmax} and the fineness ratio, particularly with landing flaps extended. If this canard airfoil is extended only during takeoff and landing, the aircraft need be artificially stabilized only for relatively short periods of time.

3. Performance Enhancement by Active Maneuver and Gust Load Alleviation /8

In conventional aircraft, the ailerons and landing flaps are used exclusively for controlling the aircraft or increasing lift, respectively. However, these surfaces are also suitable for influencing the form of the span distribution of lift under brief loads. Thus the lateral point of application of the resultant aerodynamic force for a given total lift can be shifted inward either with a positive landing flap angle or negative, symmetrical aileron angles, as a result of which wing load is reduced. Under the influence of gusts, on the other hand, the wing can only be effectively relieved via outboard control surfaces.

3.1. Maneuver and Gust Load Alleviation in Transport Aircraft

For transport aircraft, the design case ($n = 1$) and the dimensioning case ($n = n_{max}$) are far apart, so cruising performance is not impaired by active maneuver load alleviation designed for the dimensioning case. The control surfaces are deflected, proportionally to the load factor, from their neutral position, which they assume at $n = 1$, and reach their maximum angle at n_{max}. The load factor, wing flexure, bending stress or wing angle of attack can serve as the control parameter here.

If we design the wing with maneuver load alleviation and the conventional airfoil for n_{max}, the artificially relieved wing exhibits a higher stress level for $n = 1$. This lighter airfoil must therefore be reinforced slightly so that the same service life is achieved in both cases.

An additional side effect of maneuver and gust load alleviation is the destabilization of short-period longitudinal motion, which must be compensated for either by a corresponding forward shift in the center of gravity or by artificial stabilization via the elevator.

Quantitative statements are made in [3] regarding the effectiveness of the various possibilities for active maneuver load alleviation shown in Fig. 17, using the Boeing 747 as an example. In addition to the outboard aileron, which can be rotated 20° in the negative direction, and the landing flap with an angle of 30°, a freely movable articulated wingtip (rotatable to a 30° V-setting) with constant holding moment at 75% of span and a wingtip with a 10% span length freely movable about a transverse axis with a 45° maximum negative angle were also studied. The weight savings given in Fig. 17 were calculated taking the weight effect of the above-mentioned side effects of maneuver load alleviation into consideration. The greatest savings of 2970 kp [kilograms /9 force] was achieved with the wingtip rotating about a transverse axis, corresponding to a 2.8% increase in payload.

3.2. Maneuver and Gust Load Alleviation in Combat Aircraft

For combat aircraft, the design case (high steadily flyable load factor) does not differ appreciably from the dimensioning case ($n = n_{max}$), so a reduction in wing bending moment for n_{max} through maneuver load alleviation is feasible only at the expense of flight performance in the design case. Now it would be conceivable for takeoff weight in a new combat aircraft design to be less sensitive to a rise in drag caused by maneuver load alleviation than to a corresponding reduction in wing load at n_{max}. Our calculations have shown that this is not the case. In combat aircraft, maneuver load alleviation is therefore limited to reducing the rate of structural damage due to flight maneuvers and gusts. It should be pointed out in this regard that the latter factor is of subordinate importance, i.e., the service life of a combat aircraft's airframe is determined primarily by the maneuver spectrum.

The smaller fineness ratio or higher thrust/weight ratio and the smaller increase in lift for the combat aircraft cause the following effect, which is insignificant for maneuver load alleviation in the transport aircraft: Depending on whether the wing is relieved via the outboard control surfaces or the landing flaps, the angle of attack of the wing must be increased or reduced in order to maintain a given total lift. This increases or reduces thrust support of the lift force. The result of this is that the airfoil is relieved further in the former case, whereas it is again loaded in the case of maneuver load control via landing flaps.

Root bending moment is shown in Fig. 18 for various steadily flown load factors as a function of positive flap angle or of the negative symmetrical angle of imaginary outboard ailerons, using the F4 as an example. We clearly see that for combat aircraft, maneuver load alleviation with landing flaps is not feasible. On the other hand, the outboard ailerons exhibit very high efficiency. Thus root bending moment can be reduced 40% by a 30° aileron angle for $n = 4$.

The quantitative effects of active maneuver and gust load alleviation on a combat aircraft's airframe service life are presently being studied at MBB-UFE.

3.3. Lengthening the Airframe Service Life of Transport Aircraft by Active Natural-Mode Control /10

In contrast to the combat aircraft, airframe damage in the transport aircraft, in the sense of material fatigue, can be attributed largely to the action of gusts. Due to the spectral distribution of air turbulence, the low-frequency elastic modes of oscillation are excited, in addition to the rigid-body motion treated in Section 3.1, the more so the lower the natural frequency of these oscillations. The reason for this is that gust intensity increases with decreasing frequency. Since these structural oscillations are generally rather weakly damped ($\zeta \sim 0.1$), each perturbation causes a large number of load cycles.

The rate of airframe damage can be considerably reduced by artificial damping of the structural oscillations with automatically regulated control surfaces. The response of cell oscillations to the action of gusts can be reduced further if the natural frequencies of these oscillations are increased by increasing rigidity forces via artificially generated aerodynamic forces.

A control system for active natural-mode control has been developed up to the production phase in recent years for the B-52 long-range bomber. The rudder, elevator, ailerons and spoilers serve as control elements. Fig. 19 shows the lateral deflection of the fuselage tail of the B-52 during flight in turbulent air both with and without active natural-mode control. Mean amplitude is reduced by a factor of 6 by the artificial damping of fuselage bending oscillation. The damage rate is only 10% of the original value. The service life of the wing is doubled by active natural-mode control.

4. Performance Enhancement by Active Flutter Suppression

Maximum attention must be devoted to the problem of the stability of elastic modes of oscillation in the designing of modern transport and combat aircraft. The high stagnation pressure and low structural rigidities mean that the airframe must be dimensioned, to an increasing degree, by the requirement for adequate aeroelastic stability. In these "flutter-critical" designs, mechanical flutter suppression is achieved by thickening materials or applying weights, which of course decreases the cost effectiveness of the aircraft. In other cases, e.g. outboard-load flutter, no mechanical correction possibilities with acceptable costs exist at all. A remedy can be provided here only by limiting the operating range. /11

If the control system is incorporated into the design process, the various forms of flutter can be stabilized artificially with the aid of suitable sensors and control elements. The reductions in performance described above can then be avoided in the case of an aircraft subject to critical flutter.

Active flutter suppression has not yet been tested in flight. A control system for the American SST, later shelved, was designed for actively combatting two modes of oscillation, whose flutter velocity at Ma = 0.9, while greater than V_{MO}, was still considerably below 1.2 V_D. Fig. 20 shows the damping curves for these two modes of oscillation, both with and without active flutter suppression. As we see, it was possible to eliminate the flutter problem. Without this system for artificially stabilizing aeroelastic oscillations, flutter would have to have been eliminated by increasing structural weight by more than 10,000 lb.

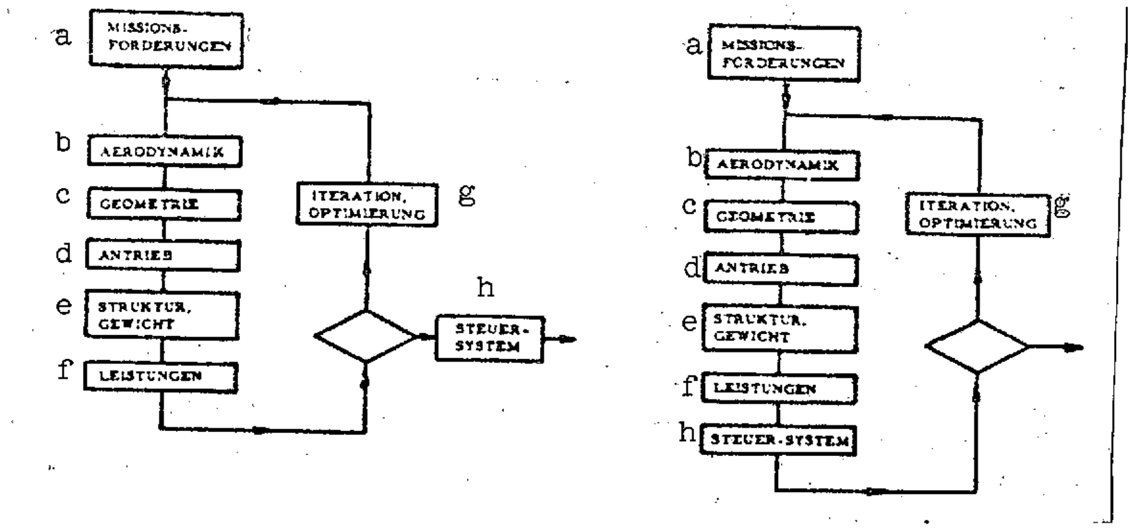
An experimental program is presently in motion at MBB-UFE which is aimed at demonstrating the feasibility of suppressing outboard load flutter. In this wind tunnel study on an aerodynamically similar model (cf. Fig. 21), the critical flutter mode with outboard loads is to be stabilized artificially via an automatically controlled damping fin mounted on the tip of the outboard load.

5. Summary

Stability requirements for the individual modes of rigid-body and elastic motion can be satisfied with considerably greater performance- and/or cost-effectiveness through the consistent application of control engineering during the designing of aircraft than by conventional means. In addition, this technology imparts properties to the aircraft which cannot be achieved by any other approach.

While other possibility for enhancing performance, such as improvements in the power plant, structural, or aerodynamic sectors, have largely been exhausted, the technology of CCV design is just beginning to open up.

/13



Conventional design CCV design

Fig. 1. Flow charts for the control configured vehicle concept as compared to conventional aircraft design.

Key: a. Mission requirements
b. Aerodynamics
c. Geometry
d. Propulsion
e. Structure, weight
f. Performance
g. Iteration, optimization
h. Control system

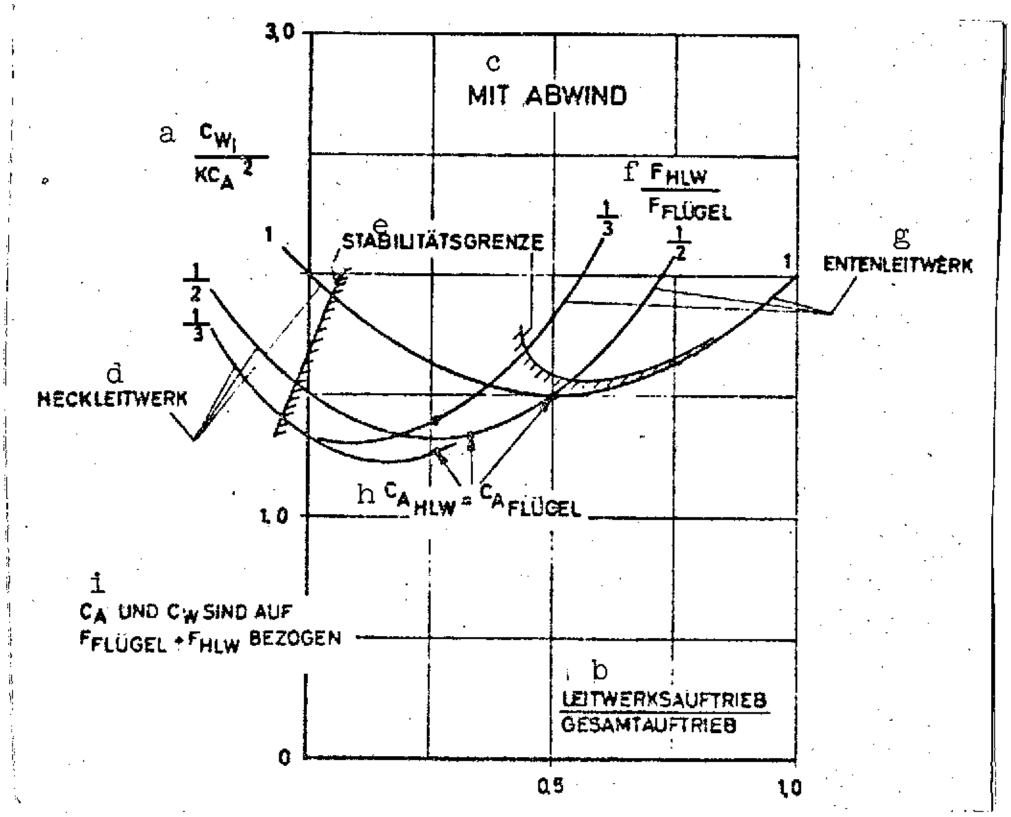


Fig. 2. Reducing drag by shifting the center of gravity aftward, with downwash effect.

Key:
a. C_{DI}/KC_L^2
b. Control surface lift / total lift
c. With downwash
d. Tail control surfaces
e. Limit of stability
f. $A_{elev.}/A_{wing}$
g. Canard control surfaces
h. $C_{L_{elev.}} = C_{L_{wing}}$
i. C_L and C_D are referred to $A_{wing} + A_{elev.}$

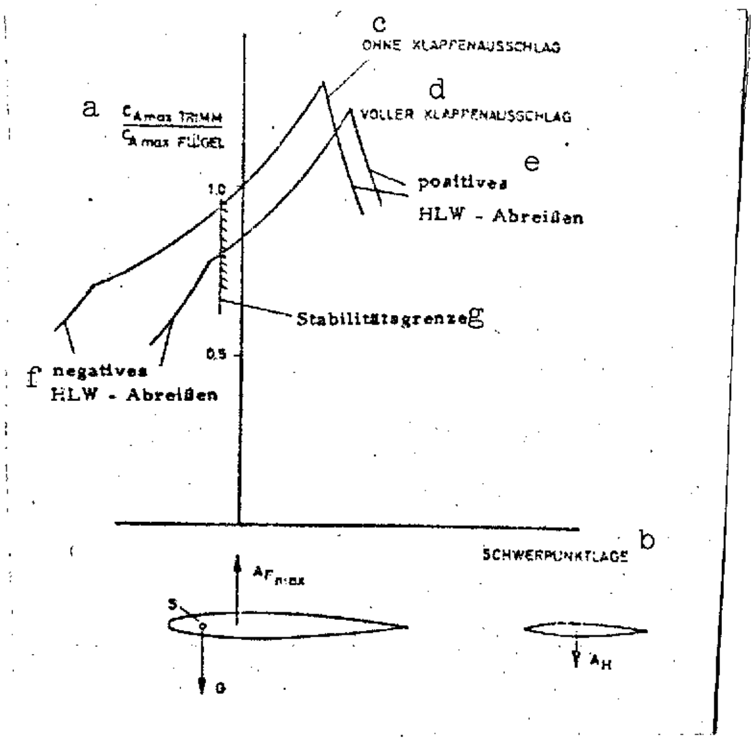


Fig. 3. Increasing $C_{Lmax,trim}$ by shifting center of gravity aftward.

Key: a. $C_{Lmax,trim}/C_{Lmax,wing}$
b. Position of center of gravity
c. Without flaps extended
d. Flaps fully extended
e. Positive elevator breakaway
f. Negative elevator breakaway
g. Limit of stability

$A_{F_{max}} = L_{wing,max}$

$A_H = L_{elev.}$

S = center of gravity

G = weight

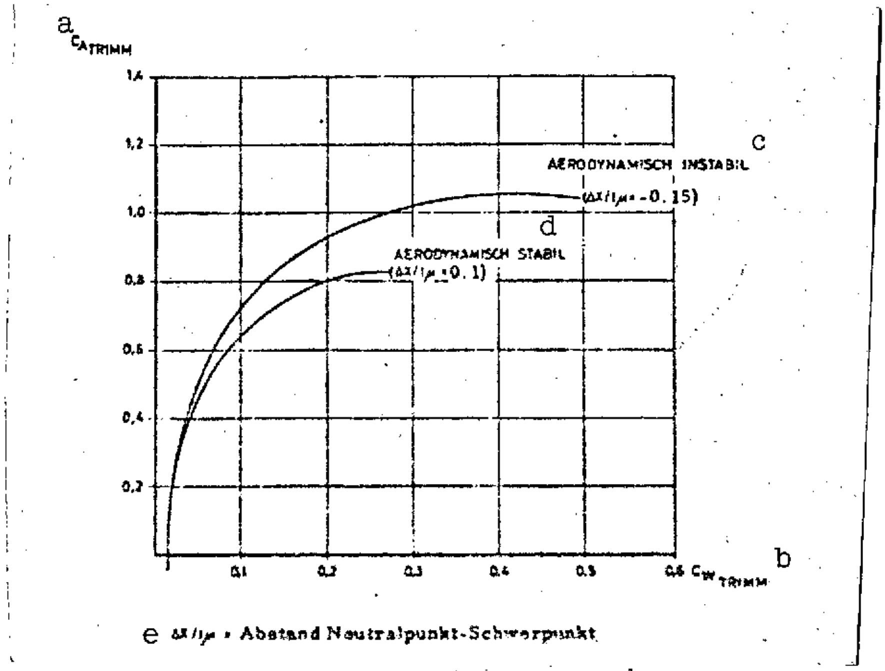


Fig. 4. Improving trimmed drag polar by dispensing with aerodynamic stability -- measured.

Key: a. C_{Ltrim}

b. C_{Dtrim}

c. Aerodynamically unstable

d. Aerodynamically stable

e. Distance between neutral point and center of gravity

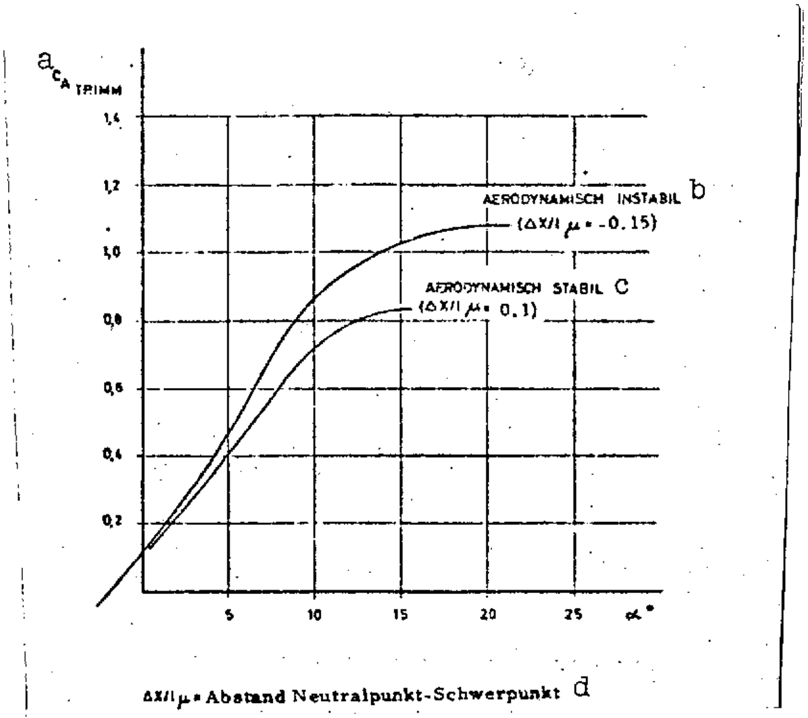


Fig. 5. Improving trimmed lift curve by dispensing with aerodynamic stability -- measured.

Key: a. C_{Ltrim}
- b. Aerodynamically unstable
- c. Aerodynamically stable
- e. Distance between neutral point and center of gravity

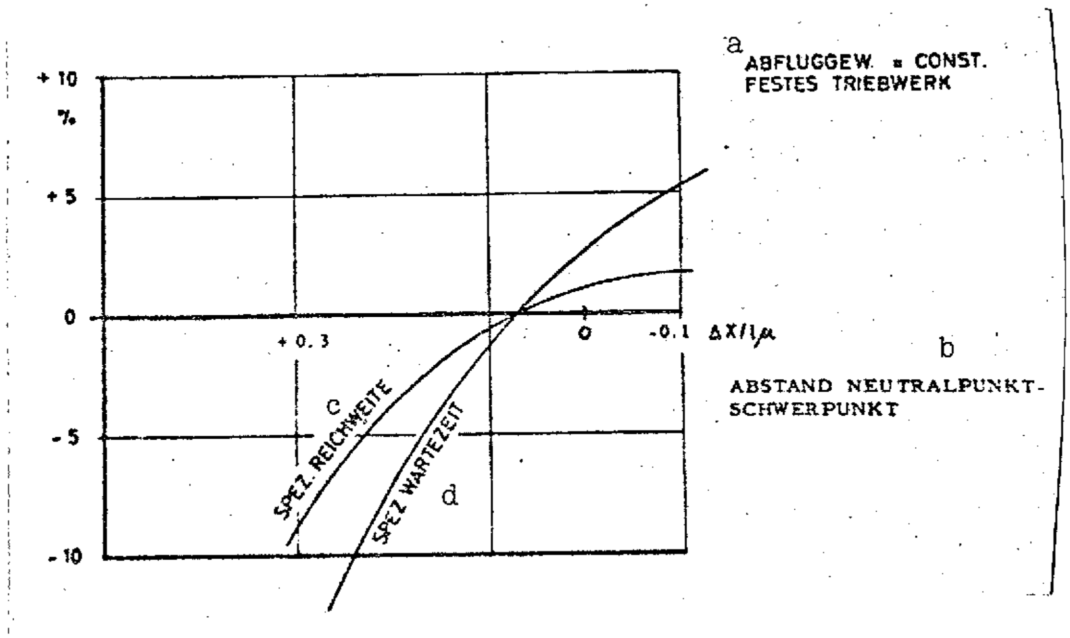


Fig. 6. Improving specific range and specific flight time by shifting center of gravity aftward.

Key: a. Takeoff weight = const., fixed power plant
b. Distance between neutral point and center of gravity
c. Specific range
d. Specific flight time

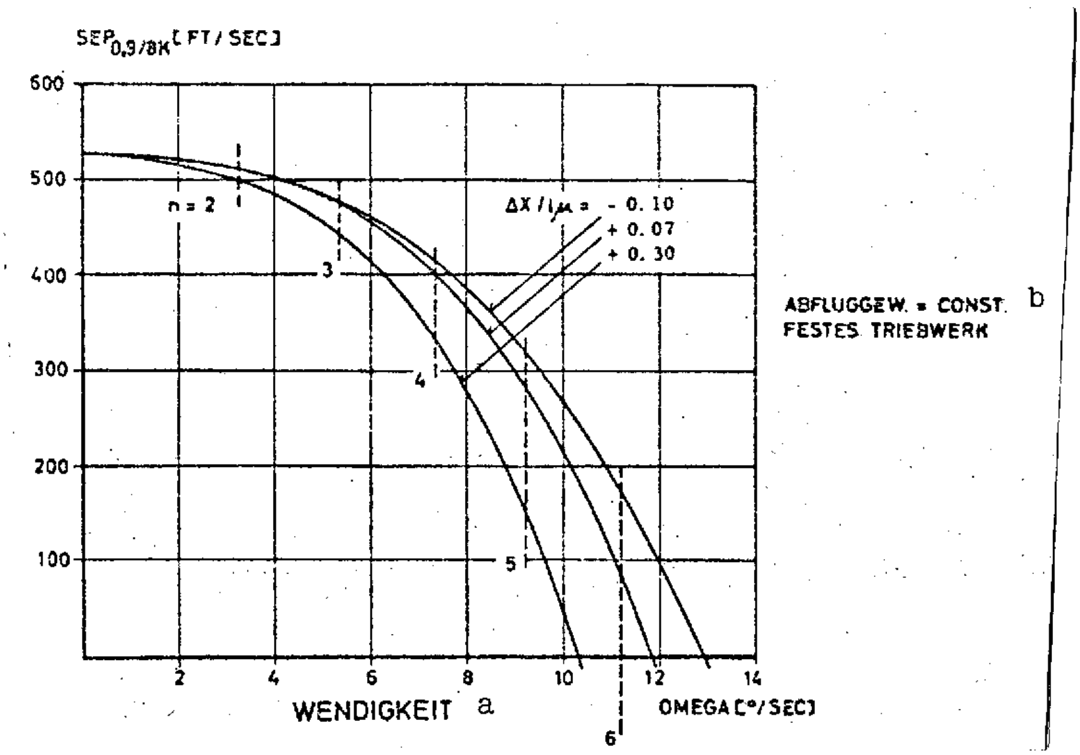


Fig. 7. Enhancing maneuvering performance by shifting center of gravity aftward.

Key: a. Maneuverability
b. Takeoff weight = const., fixed power plant

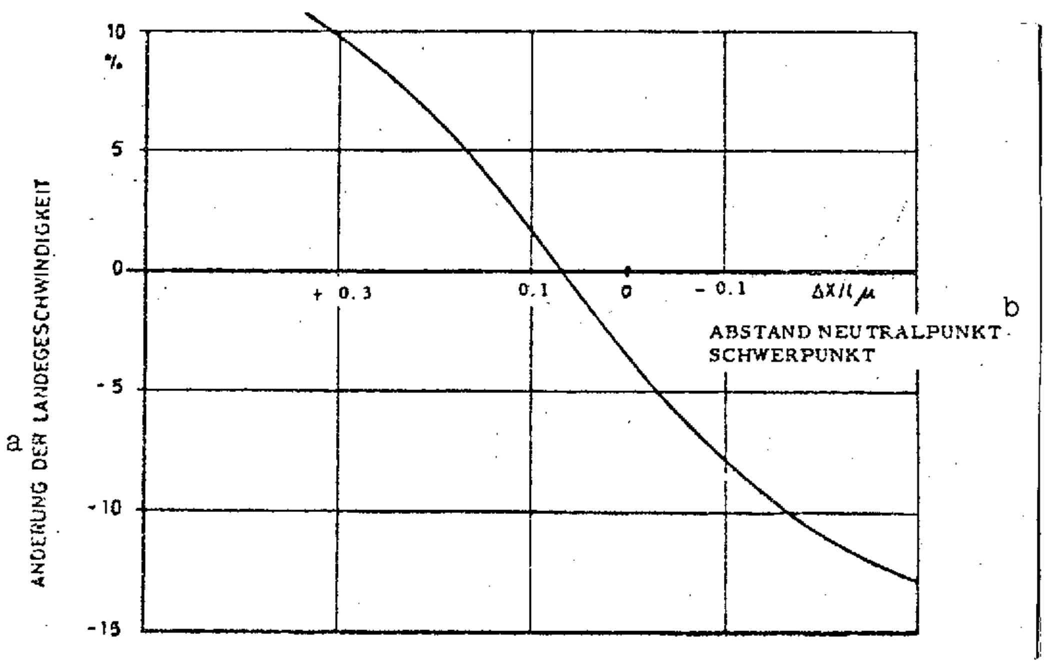


Fig. 8. Reducing landing speed by shifting center of gravity aftward.

Key: a. Change in landing speed
b. Distance between neutral point and center of gravity.

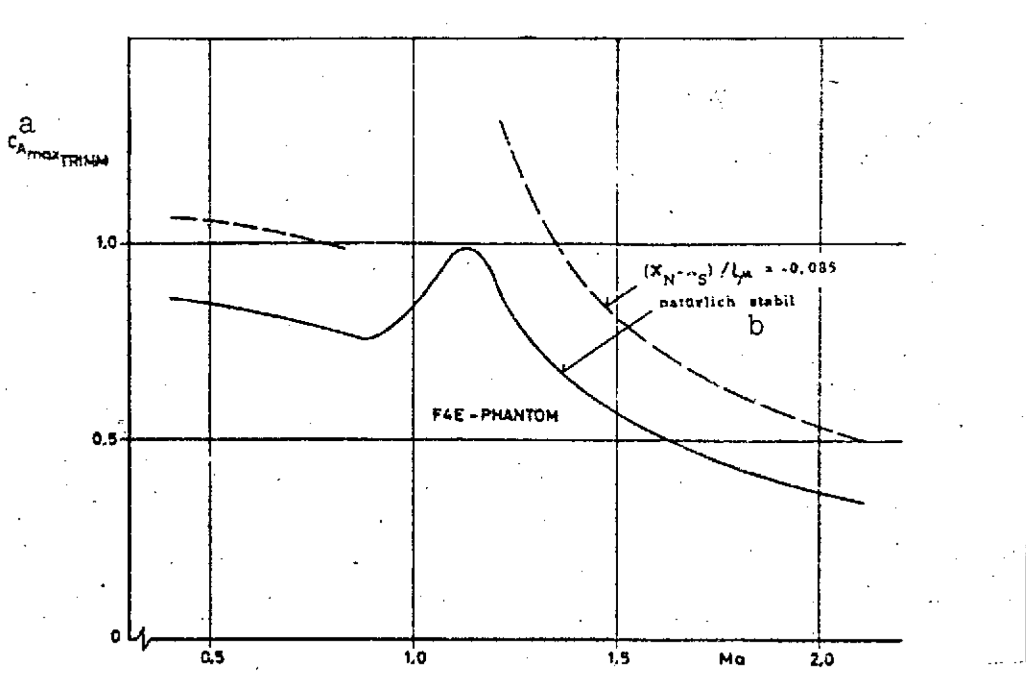


Fig. 9. Raising $C_{Lmax,trim}$ by shifting center of gravity aftward, as a function of Mach number (from AIAA Paper 71-764).

Key: a. $C_{Lmax,trim}$
b. Inherently stable

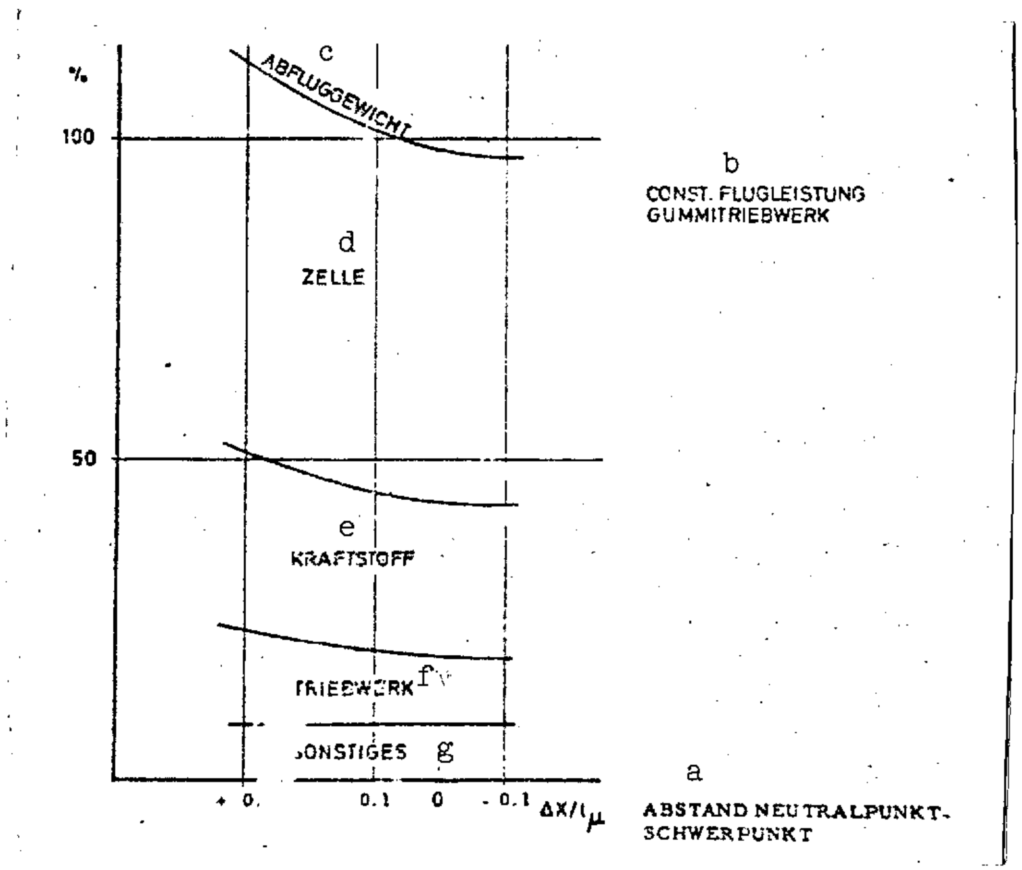


Fig. 10. Reducing the takeoff weight of a new design with flexible power plant by shifting center of gravity aftward.

Key: a. Distance between neutral point and center of gravity
b. Constant flight performance, flexible power plant
c. Takeoff weight
d. Airframe
e. Fuel
f. Power plant
g. Other

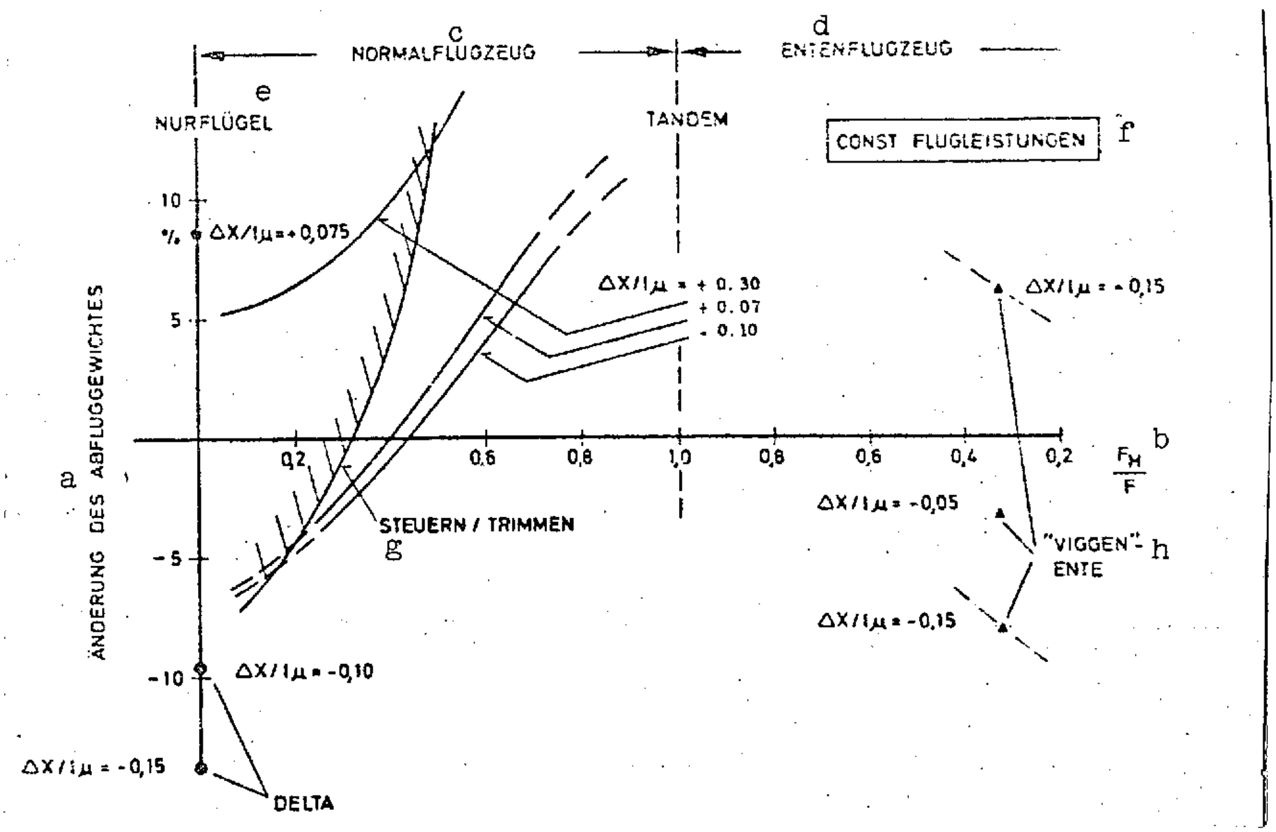


Fig. 11. Increase in takeoff weight with elevator area ratio.

Key: a. Change in takeoff weight
b. $A_{elev.}/A$
c. Conventional aircraft
d. Canard aircraft
e. Flying wing
f. Constant flight performance
g. Control/trimming
h. "Viggen" canard

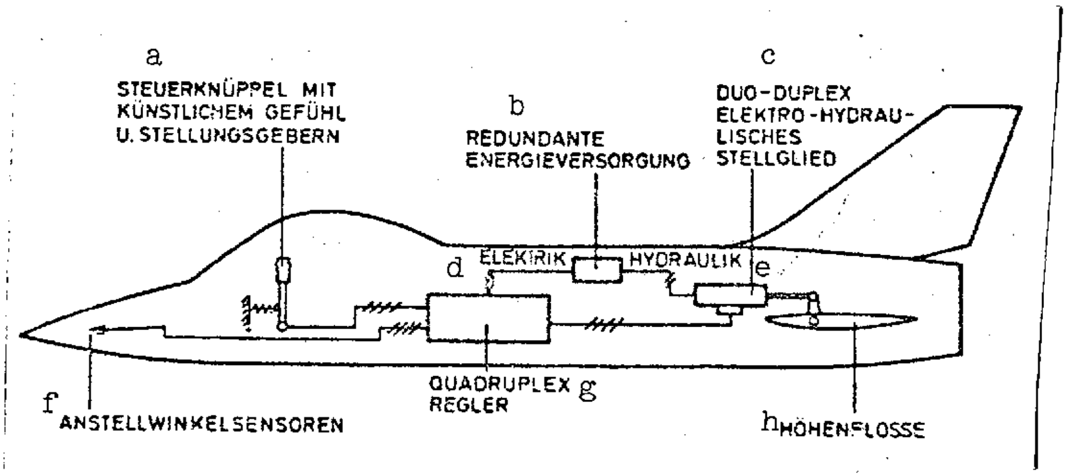


Fig. 12. Diagram of all-electric control and regulating system for the artificially stabilized aircraft.

Key: a. Stick with artificial "feel" and remote position indicators
b. Redundant power supply
c. Duo-duplex electrohydraulic actuator
d. Electrical
e. Hydraulic
f. Angle of attack sensors
g. Quadruplex regulator
h. Elevator

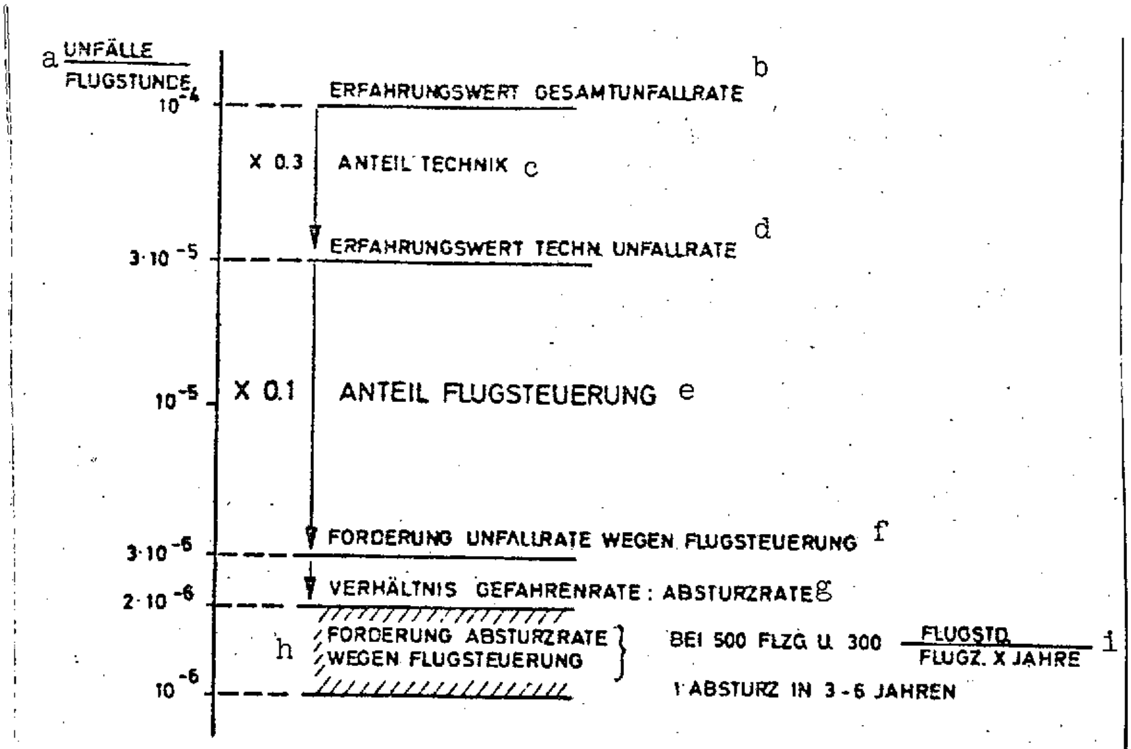


Fig. 13. Derivation of safety requirements.

Key:
a. Accidents / flying hours
b. Empirical total accident rate
c. Engineering component
d. Empirical engineering-related accident rate
e. Flight control component
f. Required accident rate related to flight control
g. Ratio of hazard rate to crash rate
h. Required crash rate related to flight control
i. For 100 a/c and 300 flying hours / / (a/c·year), 1 crash in 3 to 6 years

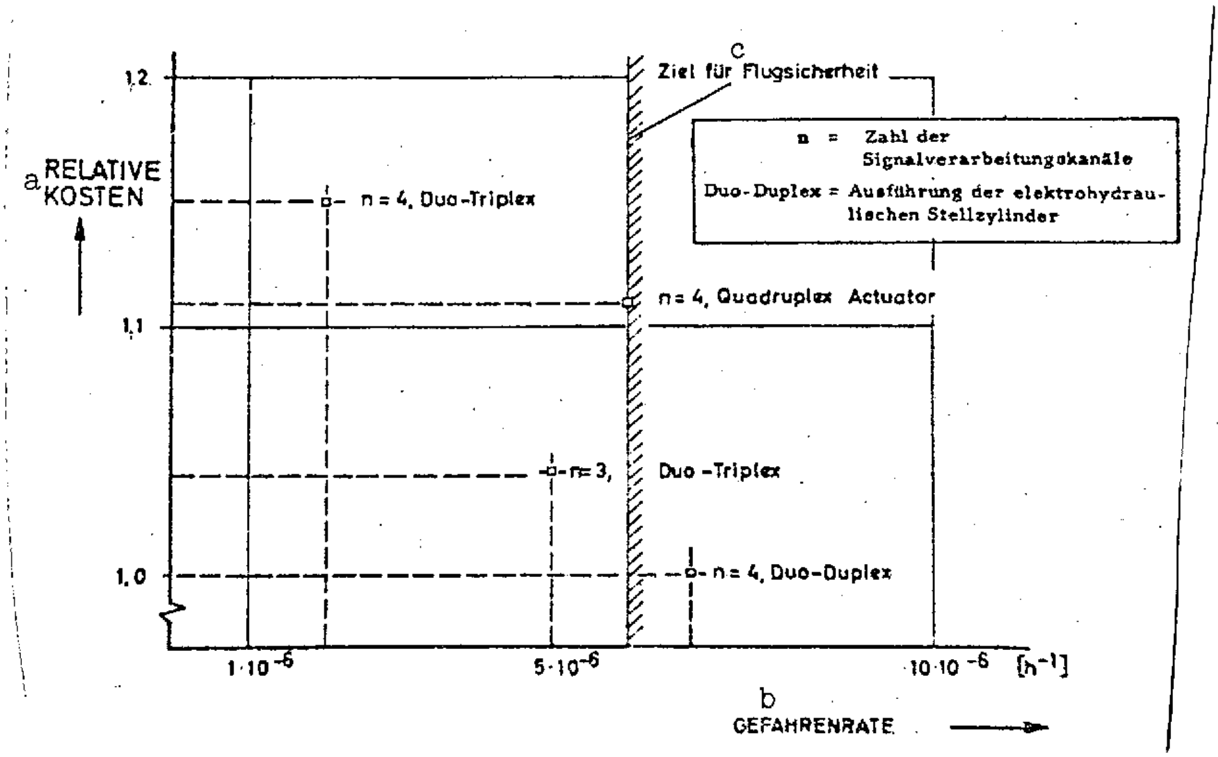


Fig. 14. Comparison of flight safety and costs.

Key: a. Relative costs
b. Hazard rate
c. Flight safety target

n = Number of signal preparation channels
Duo-duplex = electrohydraulic actuator cylinder design

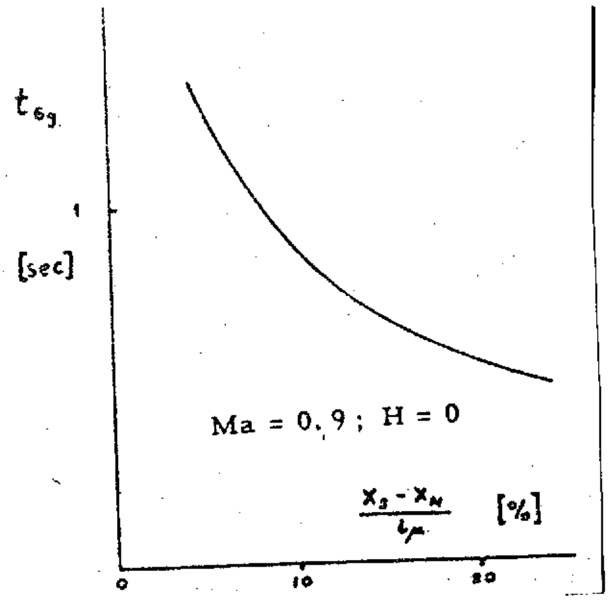


Fig. 15. Time in which the load factor on an uncontrolled aerodynamically unstable combat aircraft changes by 6 g, as a function of instability index.

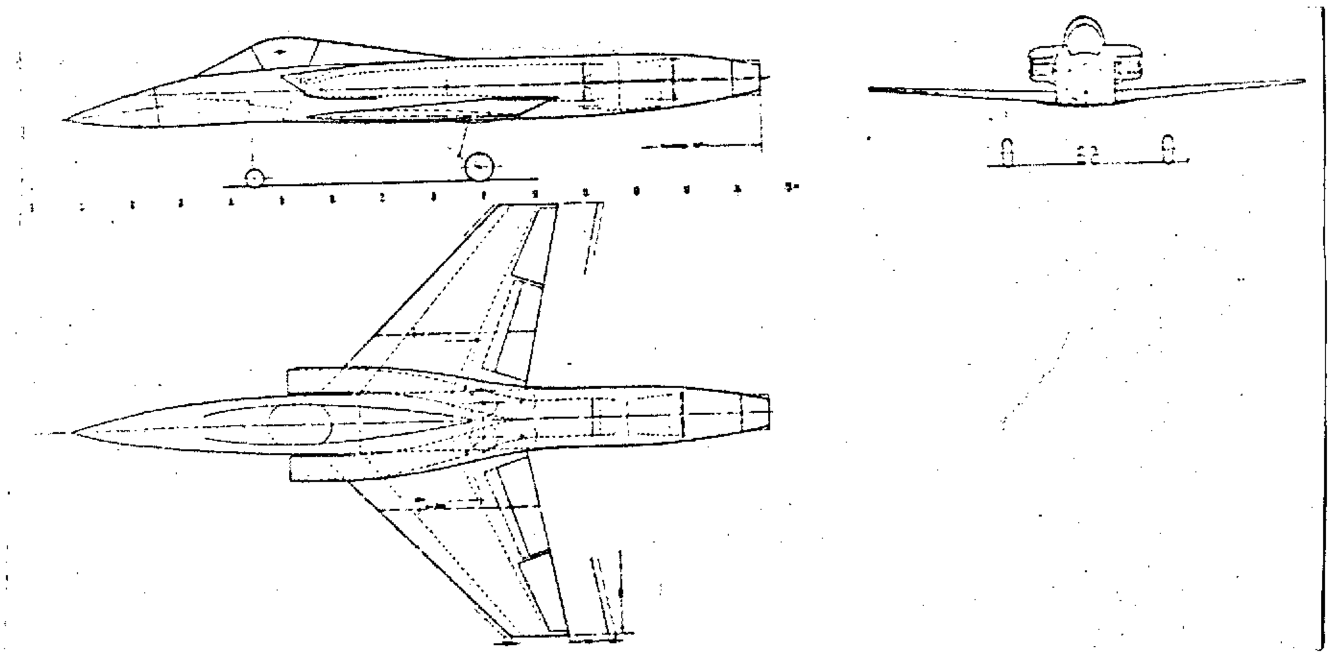


Fig. 16a. Combat aircraft with dynamic pivoting nozzle and sliding wings as an example of new design possibilities for combat aircraft.

/21

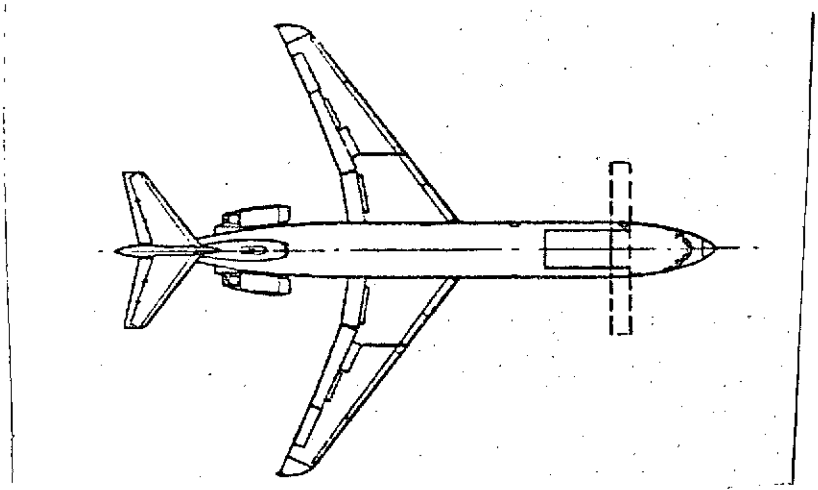
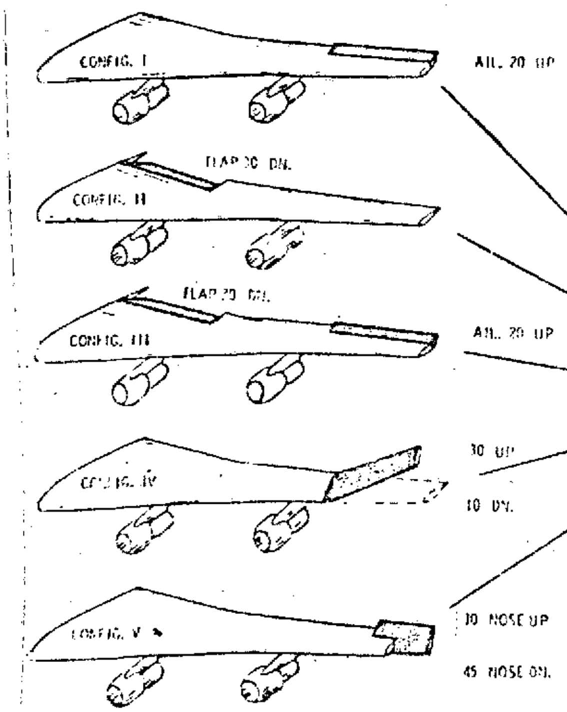


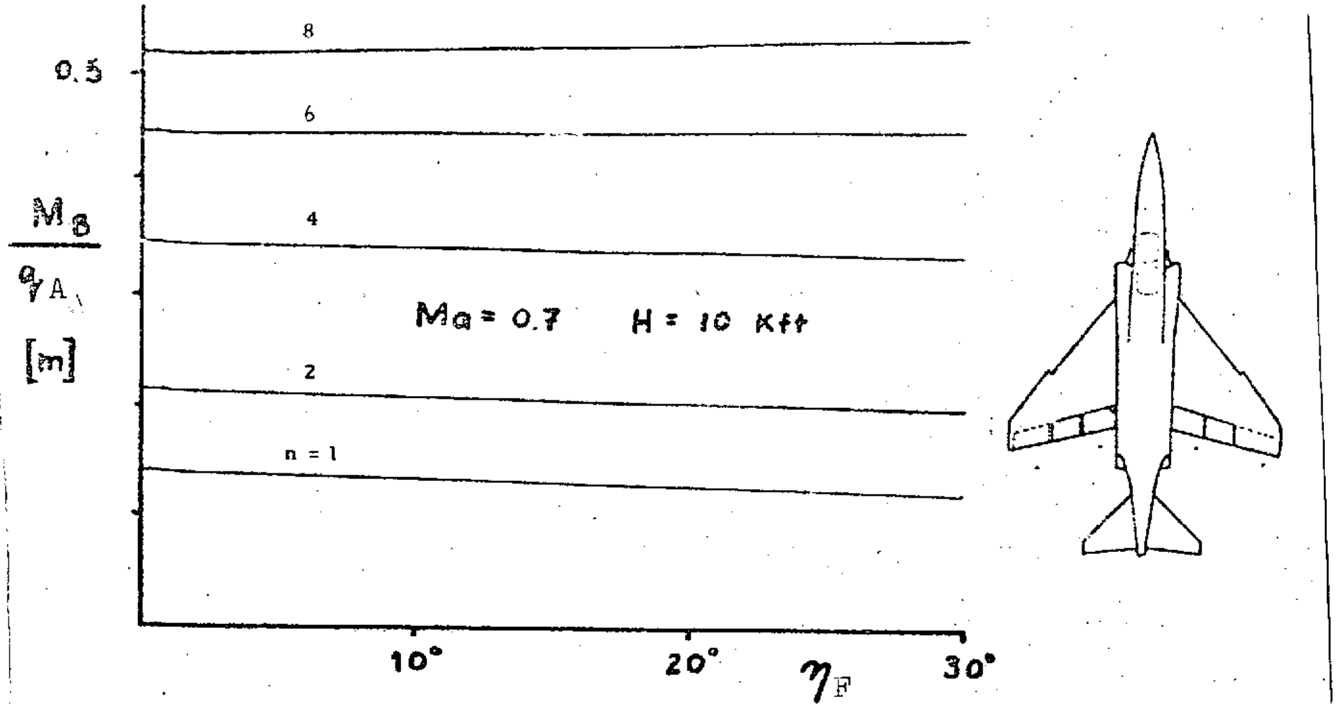
Fig. 16b. Extendible nose control surface system, as an example of new design possibility for transport aircraft.



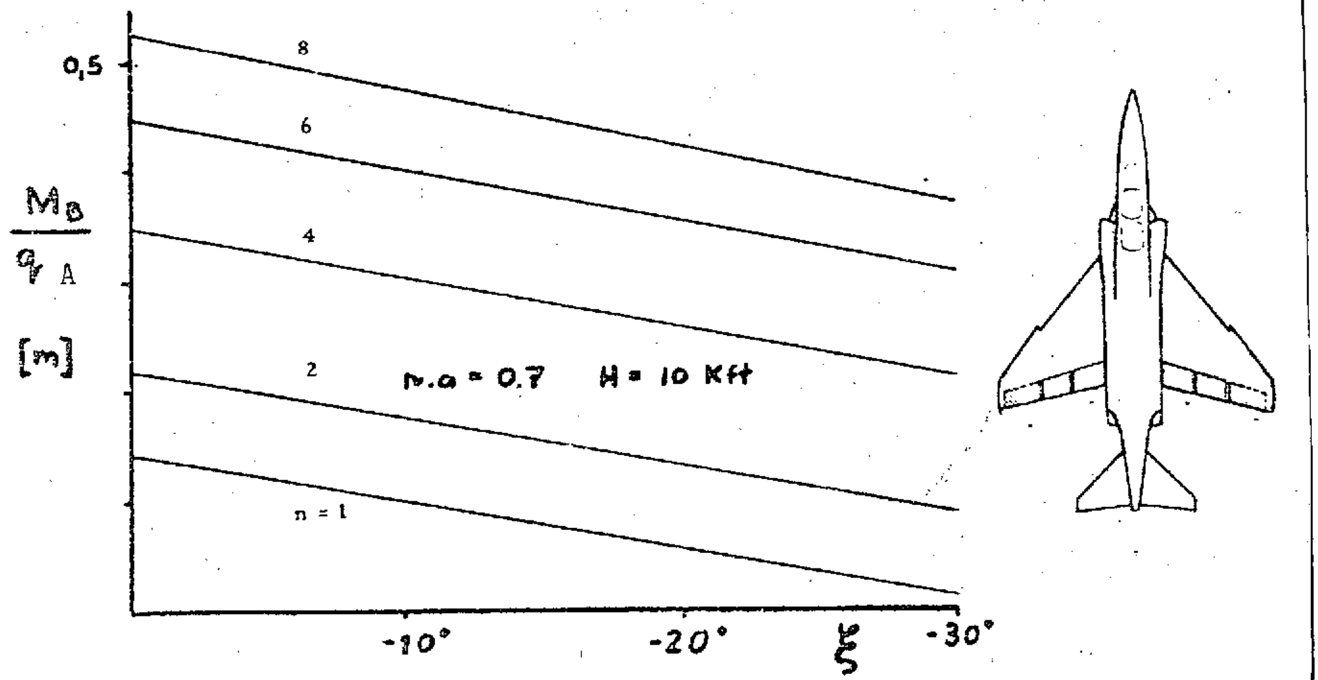
a Strukturgewichtseinsparung [kp]	b [% tragender Flügelstruktur]
1290	6.5
540	2.8
1830	9.3
2580	13.2
2970	15.1

Fig. 17. Possibilities for active maneuver load alleviation studied for transport aircraft and their effect on structural weight, using the Boeing 747 as an example (from [3])

Key: a. Savings in structural weight
b. % load-bearing wing structure



Root bending moment as a function of landing flap angle



Root bending moment as a function of symmetrical outboard aileron angle.

Fig. 18. Maneuver load alleviation, with the F4 as an example.

/23

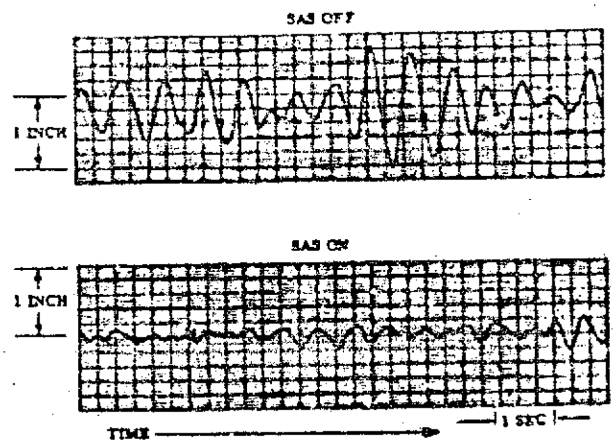


Fig. 19. Reducing the structural response to gust effects by means of active natural mode control. Lateral deflection of fuselage tail in B 52 with and without active structural oscillation damping (from [5]).

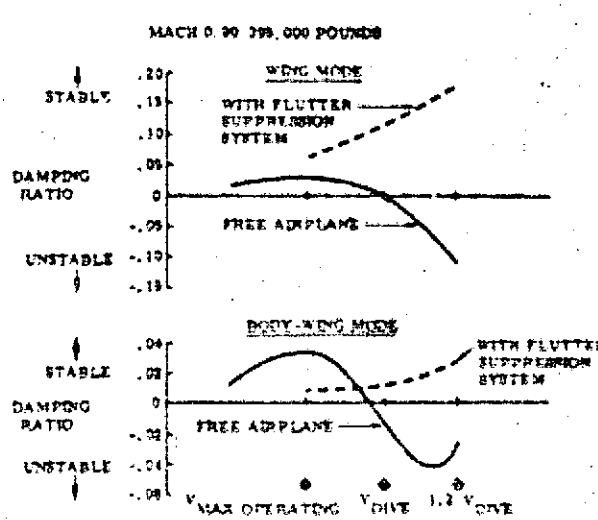


Fig. 20. Active flutter suppression, with the American SST design as an example. Damping curves for two modes of oscillation versus equivalent flight velocity with and without active flutter damping, Ma = 0.9 (from [5]).

/24

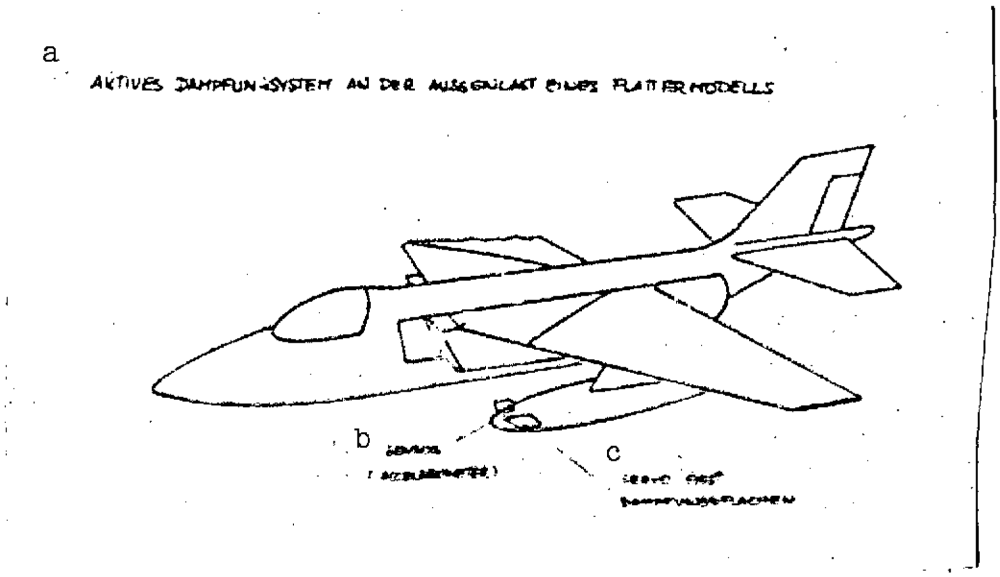


Fig. 21. Demonstration of feasibility of suppressing outboard load flutter with active flutter damping. Test design for wing tunnel measurement on an MBB flutter model.

Key: a. Active damping system on outboard load on a flutter model
b. Sensor (accelerometer)
c. Servo-controlled damping surfaces

REFERENCES

1. "Artificial stability," MBB Brochure UFE 869-72. /12

2. "Jet-controlled combat aircraft," 1971 ZTL Program, MBB Report No. UFE-791-71. Part 1: "Overview report." Part 2: "Configurations and flight performance." Part 3: "Flight characteristics, control system, flight safety." Part 4: "Flight testing program."

3. White, R.J., "Improving airplane efficiency by use of wing maneuver load alleviation," J. Aircraft 8(10).

4. Wykes, J.H., "Structural dynamic stability augmentation and gust alleviation of flexible aircraft," AIAA Paper 68-1067.

5. Thompson, G.O. and Kass, G.J., "Active flutter suppression -- an emerging techology," J. Aircraft 9(3).

6. Holloway, R.B., Burris, P.M., and Johannes, R.P., "Aircraft performance benefits from modern control systems technology," J. Aircraft 7(6).

7. Carline, A.J.K., "Economic impact of applying advanced technologies to transport airplanes," AIAA Paper No. 72-758.